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"Digital Workflow in Maxillofacial Prosthodontics: An Insight"

Abstract:

From its inception to now dentistry has made its way covering great milestones in terms of invention and precision to provide us with better working conditions and increased comfort for both clinicians and patients. To add up, is the remarkable innovation: CAD-CAM technology, which allow the dentists to provide a better and quality care to their patients. While restoring a facial defect the prosthesis should ideally be customized to put back the anatomy as accurately as possible. This process is difficult and time consuming & demands a high level of artistic skill to form a mirror image & achieve a good aesthetic match. The present time evolution of CAD/CAM is focused on methodical and swift integration and automation of the elements of design and manufacturing along with the development of new algorithms. This article reviews the development and availability of various digital technologies for the designing and manufacturing of different maxillofacial prostheses.

Key-words: Digital dentistry, Maxillofacial Prosthodontics, CAD/CAM, Digital impression, Rapid prototyping.

Introduction:

The conventional method of fabricating maxillofacial prostheses includes several complex steps; it is a labour-intensive and time-consuming task, and the final results mainly depend on the experiences and skills of the clinician. Digitalization in this field has opened up a new approach to the fabrication of maxillofacial prostheses, as the technology has taken over the field with a reduced the manual labour, more precision and perfection.[1]

There are many commercial CAD/CAM packages available for direct usages that are user-friendly and very proficient.[2]

The key elements involved in the digital rehabilitation are:

1. Visualization
2. Design
3. Manufacture
4. Evaluation

Digital visualization is done using various medical imaging techniques, namely, computed tomography (CT), cone beam computed tomography (CBCT), and magnetic resonance imaging (MRI). Other than these various non-medical techniques including, intra oral scanners, LASER surface and 3D photogrammetry systems for fabrication of 3D models.

Designing and modelling depends on the type of data acquisition. This plays an important role in the digital workflow as there exists the ability of sculpting the anatomic details and deforming the virtual clay models into the required form.

The manufacturing technique is known as 3D printing or rapid prototyping. These include stereo lithography, LASER sintering, fused deposition modelling and inkjet based systems.

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Evaluation of the prostheses in terms of form and function include subjective and objective techniques, which decide the ultimate success and usefulness of the prostheses. [3]

History:

Computer-aided design/computer-aided manufacturing (CAD/CAM) technology was born in the early 1980s. Dr. Duret was the first to patent CAD-CAM in dentistry. Since then, the technology has progressed in two directions: intra-operative applications for single-appointment restorations (using prefabricated ceramic monoblocks) and CAD/CAM systems for commercial manufacturing centres and dental laboratories.[4]

Why Digitalisation?

The use of computer-based technology and virtual reality, which allows the dental surgeon to recreate real-life conditions in patients, is crucial to the future of dental practise. It is the procedure of making a digital reprint of something that originally was an analogue; which can be either a document, an artefact, sound, performance or a natural phenomenon. By scanning, tracing, or utilising a graphics tablet, or by employing an analogue to digital conversion equipment, an image or signal is converted into digital code.

▶ Advantages:

1. Reduced labour: It reduces the labour of both dentist and technician
2. Time effectiveness: Conventionally it takes multiple appointment, days and personal involvement to finish restorations. CAD/CAM can shorten this to a few hours or minutes.
3. Quality control: The quality of CAD/CAM restorations is extremely high because measurements and fabrication are so precise. There are almost no internal faults in milled items when using a prefabricated ceramic block whose quality has been validated by the manufacturer.
4. Review and correction of preparation: Scanning an image and viewing it on a computer screen allows the dentist to check the preparation prior to taking the impression and make instantaneous revisions to the preparation.
5. Patient is freed from the trouble of impression and impression materials.
6. Newest innovations in CAD/CAM systems also allow to view and develop occlusion in a dynamic state.

Conventional Materials to Digital Tools: A Paradigm Shift:

Materials for maxillofacial prosthetic reconstruction range from hard, stiff alloys, ceramics, and polymers to soft, flexible polymers and their formulations as latex and plastisol. But, as yet, no material has emerged that possesses all the distinct and desirable characteristics.[5]

● Digital Workflow Tools:

With the advent of three dimensional (3D) scanners, 3D software and rapid prototyping technology, the traditional impression, modelling and production techniques can probably be replaced by. This digital technology can be used for obtaining better results in shade matching or adding surface characters and details. The digital technology in maxillofacial prosthodontics is making progress and has tremendous potential in making the workflow more comprehensible.

1. Digital data collection tools

A wide variety of 3D scanning technologies are at hand for acquisition of maxillofacial defects. Amongst these technologies, transmissive scanning technologies, like cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) have been used with success to replace atraditional impression for a facial prosthesis. [6] The optical 3D scanners mostly used for facial scanning are the laser scanner, the stereo-photoscanner and the structured light scanner[7, 8]

● LASER Scanner:

The laser scanner consists of a laser line that is moved relative to the object being scanned. The resulting distortion of the light pattern on the subject is caught on a charged couple device (CCD) gadget when seen from an offset angle. Triangulation is used to calculate the 3D co-ordinates of the object's surface. Laser scanners have proven to be accurate and have been used successfully in digital acquisition for the production of auricular, nasal and orbital prostheses.[9]

● Stereo-Photo Scanner:

Stereo photogrammetry uses multiple images of the same object taken from different viewpoints to reconstruct a 3D model. On each image, common points are identified, and a virtual ray is built from each camera location to these spots on the object. The distance to specified spots may be estimated using the technique of triangulation because the distance between the cameras and the angle of the cameras are known. A fundamental limitation of stereo photogrammetry is that obtaining correspondence between points on consecutive images is extremely difficult, commonly mentioned as the “correspondence problem”. Photogrammetry scanners have been proven to be accurate when used for measurements of distances between anatomical landmarks on the face of a subject but the resolution of the 3D model produced by most photogrammetry scanners is too low to reproduce fine skin details. 3D models produced from a photogrammetry scan were shown to be less accurate than 3D models produced with CBCT. Photogrammetry scanning has been used for nasal and orbital prostheses.[9, 10]

● Structured light scanners:

These work by projecting a known light pattern onto the object to be scanned. The image of the item with the projected pattern is captured by photo or video cameras. For the range measurement of the 3D scanning process, structured light scanners can use a variety of methods. The scanner's technology will most likely use triangulation to calculate the distance between the projected light point or line(s) on the object and the sensor. Structured light scanners have also been proven to be accurate for measuring facial landmarks, i.e., distances and angles on the face of a subject. Structured light scanners have been used for auricular nasal and orbital prostheses.[9]

2. Designing tools:

Comprehensive software is needed to design a final model of the facial prosthesis that can be rapid prototyped.

- Commercially available software:Geomagic Studio (3D Systems, Rock Hill, SC, USA), Zbrush (Pixlogic Inc.)[11], Rapidform (INUS Technology, 3D Systems, Rock Hill, USA), Rhinoceros (Robert McNeel & Associates, Free Form (SensAble Technologies, owned by 3D Systems, Rock Hill, USA)[12], Magics (Materialise, Leuven, Belgium), 3-Matic (Materialise, Leuven, Belgium), Solidworks (Dassault Systèmes) and Cinema 4D R18 (MAXON Computer, GmbH) [13]

- Open-source software:Meshmixer (AutoDesk Inc.), Makerware (Makerbot Inc.) and C++ and Visual Toolkit (VTK) [13]

3. Processing tools:

In a digital workflow the production phase of the prosthesis can be performed by rapid prototyping. Rapid prototyping is a technique for creating a digitally created model quickly.

There are two ways for rapid prototyping, viz., subtractive or by additive manufacturing. [9]

- In subtractive manufacturing, computer controlled mechanical tools are used to cut away (milling) material to achieve a desired model. This technology is also known as “computer numerically controlled (CNC) machining”. [9]
- Among the additive manufacturing techniques, the following procedures are employed: fused deposition modeling (FDM); digital light processing (DLP); selective laser sintering (SLS); and stereo lithography (SLA). [13]

For the production phase, the use of printable silicon materials with the proper mechanical properties would be the first choice as these materials are the most widely applied materials for facial prostheses. Silicones can be matched with skin colors by adding pigments, have an excellent detail reproduction capacity and can reproduce details up to 20 µm. [9]

Digital Workflow:

The basic question here is: Is the full digital workflow an option for maxillofacial prosthesis manufacturing? This is followed by a secondary question: Is the used software accessible to all dental technicians involved in maxillofacial prosthodontics? [13]

Everyday prosthodontics involves impression and mold making. For different types of prostheses, the cascade of steps typically involves impressions of the area of interest, cast reproduction, wax modelling, mold making, and, finally, creation of the final prosthesis. In the last decade, major improvements were introduced through rapid prototyping stereo lithography (STL), whereby information captured by imaging is directly transferred into acrylic resin models of the bony structures involved. [14]

1. Digital Impression:

Dr. Mormann and Dr. Brandestini originated, the first profit oriented digital impression system the CEREC 1, in 1985. [15] Dr. Mormann also licensed today Sirona Systems. CEREC 2, CEREC 3, CEREC 3D were introduced in 1994, 2000 and 2003.[16]

It is feasible to procure noncontact 3D facial soft tissue quantification and create 3D anatomic models with the recent advances in imaging technologies. Digital 3D facial scanning is a rapidly evolving technology with applications in biomedical engineering, 3D animation, and dentistry.

Two main types of extra oral optical 3D scanners are based on fringe projection technology and 3D laser scanning system.

Recent studies revealed that scanning of the 3D geometry of dental tissues with intraoral scanners demonstrates the accuracy and precision required to capture complex tooth morphology.

IOS has a handheld camera, computer and software. After identification of the point of interest, software, under a light projection, assembles individual images and/or videos recorded by the camera [15]

Currently four types of imaging technologies are in practice: Triangulation, Parallel confocal imaging, Accordion fringe interferometry (AFI) and Three-dimensional in-motion video.

The scanning systems commercially available are: ITero, Lythos, Fast scan, Plan scan, True definition, Trios, Carestream CS 3500 and CEREC.

2. Prosthesis Designing:

A 3-dimensional (3D) soft tissue geometry produced using a digital image can be further used to design the prosthesis and manufacture a mold, or directly print the prosthesis.[17] The design of the maxillofacial prosthesis can be obtained using either open-source (OS) or commercially available (CA) softwares.

One of the most extensively used digital format is STL (Standard Tessellation Language). Other formats are PLY files, Polygon File Format. An image editing programme is used to convert DICOM (Digital Imaging and Communication in Medicine) data obtained from medical scanning (e.g.,CBCT) and generate a surface mesh (Stereo lithography file format-STL) using a threshold tool, which allows a range of values to be set from the data to be retained while ignoring data that falls outside the range.[18]

3. Processing:

Two different propositions are utilised in dentistry/medicine to fabricate a physical prototype (model): subtractive and additive.

The subtractive technique is generally achieved by the conventional numerical control machining (CNC). An optical or contact probe surface digitizer that can recreate the outward structural data but not the inside tissue data of the preferred anatomical object provides CNC machining data. Therefore, CNC machining is generally used for fabrication of typically small prototypes; example metallic and/or ceramic crowns in dentistry. [19]

Additive technology, on the other hand, can produce any complex structures or internal geometries with small details. This is routinely called the "Layered manufacturing", in which an object's CAD design is framed into cross-sectional layer sketch from the bottom up, bonding one to another and then the numerical files transform into virtual trajectories controlling additive process of the material to produce the entity called a prototype. [19]

- **Rapid Prototyping:**

It produces physical prototype in a layer by layer manner from their CAD model data, CT and MRI scan data, and any 3D digitised data. It was developed in three phases; as: [20, 21]

1. First prototyping phase: in this period, manual prototyping has been created by efficient craftsman.
2. Second prototyping phase: in the mid of 1970s, a soft prototype model was stressed virtually, with precise material using 3D curves.
3. Third prototyping phase: begun in 1980s. In this era, layer by layer technique have been taken into consideration to create a prototype.

The frequently adopted RP technologies are:

- Stereo lithography (SLA)
- Inkjet-based system (3D printing - 3DP)
- Selective laser sintering (SLS)
- Fused deposition modelling (FDM)

Stereo lithography: It employs a computer-controlled moving laser beam to layer by layer construct the desired things from a liquid using additive manufacturing or 3D printing data. [19]

The following are the parts of a stereo lithography device: [22]

1. A liquid resin-filled container (acrylic or epoxy)
2. Inside the container, a movable elevator platform
3. An ultraviolet laser with top-mounted beam focusing optics
4. Controlling the laser beam with a deflecting mirror

- The laser beam draws onto the resin's surface, initiating local liquid polymerization. The laser solidifies the borders first, then the inside components.

- Once the layer is polymerized, the elevator platform descends a predetermined distance, usually 0.1-0.5 mm, burying the model in the liquid resin bath.
- The surface is smoothed out using a sweeper, and the resin is levelled. As a result, a fresh liquid layer covers the firm layer, and the sketching process continues.
- Model is finished by draining excess liquid resin and curing the object surfaces under UV floodlights.[22]

Selective laser sintering: It was discovered in the middle of 1980s by Dr. Carl Deckard and Dr. Joe Beaman. It forms the acquired three dimensional structures by fusing small powdered particle materials with a high power laser (CO_2 laser). [19]

The diffusion system of powder is like the action of the build cylinder, in which a piston moves upward to distribute a proper amount of powder for each layer further getting exposed to laser beam. Subjoining of the laser beam and powder will increase the temperature to the melting point, causing the fusion of powder particles forming solid structure. After finishing of the first layer, extra powder layer will be added by a roller technique over the layer which is scanned previously. [23, 24]

Inkjet-based system or 3dp : A steady measured quantity of the raw powder-form get transfer from a container by a moving piston.

- A roller suppresses the powder at the top of the fabrication chamber.
- The multi-channel jetting head will deposit the liquid adhesive in a 2D pattern onto the powder, bonding and forming a layer of the object.
- When a layer is formed, the piston will distribute and join the next powder layer.[25]

Fused deposition modelling: A thermoplastic material is used in a layer by layer manner through a temperature-controlled head. It works in three axes, drawing the model one layer at the same time. A fine plastic bead is dropped by the nozzle when it is moved over the stand table. This forms the first layer. The plastic keeps solidifying and bonding with layers below, once released from the machine nozzle. [26, 27]

Conclusion:

Regardless of age, fabricating a facial prosthesis is a tough task for both the physician and the patient. It requires several visits involving potentially uncomfortable and stressful procedures that are even more demanding for a child with minimal communication skills. Digital imaging, computer-aided design, internet connection, digital manufacturing, and new materials have unquestionably sped up the diagnostic process and enhanced treatment outcomes.

To date, the software and interfaces used in the development and design of maxillofacial prosthesis are expensive and not commonly utilised for this purpose, making the procedure more complicated, demanding more uniqueness, and only available to highly skilled dental experts or CAD engineers. With the growing demand for a digital approach to maxillofacial rehabilitation, more support from the software designer or manufacturer will be required to create more user-friendly and accessible modules for existing dental software, similar to those commonly used in dental clinics and laboratories.

Duret once stated "The systems will continue to improve in versatility, accuracy, and cost effectiveness, and will be a part of routine dental practice in coming time". The future of dentistry to a great extent will be influenced by digital systems.

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